Radiation Pattern Analysis for Reflector Antennas using the Near-Field Measurements of Primary Feed

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Abstract — **We investigate a radiation pattern analysis method for reflector antennas using near-field measurements of primary feed. Using the plane-wave spectrum obtained through near-field measurement, it is possible to find the incident electromagnetic field not only at an arbitrary plane, but also at each point of the reflector. This paper describes the analysis method, and verifies its validity by using array-fed reflector antenna.**

Index Terms — **Plane-wave Expansion Method, Near-Field Antenna Measurements, Reflector Antennas.**

1. Introduction

The near-field antenna measurements using the plane-wave expansion method, it is possible to evaluate various antenna characteristics via field conversion. We investigate the application of the plane-wave expansion method to analysis of a radiation pattern mediated by a reflector. With the generally plane-wave expansion method, field conversion for an arbitrary plane is conducted by using a Fourier conversion, but it is also possible to find the electromagnetic field at arbitrary positions along the reflector surface. This paper describes an analysis method for the radiation pattern of a reflector antenna using planar near-field measurements of the primary feed, and verifies the validity of this analysis method using array-fed reflector antenna.

2. Analysis

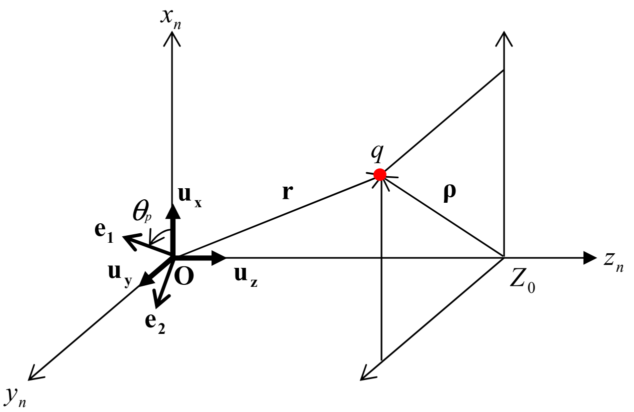


Fig. 1. Coordinate system for near-field measurement.

Figure 1 shows the near-field measurement coordinate system (x_n, y_n, z_n). The unit vectors for each axis are $\mathbf{u_x}$, $\mathbf{u_y}$, $\mathbf{u_z}$, respectively. The plane where z_n=Z$_0$ that is parallel to the x_ny_n-plane is taken to be the near-field measurement plane. When the vector $\mathbf{r}$ is given indicating an arbitrary observation point q on this plane, the radiated electric field $\mathbf{E}_q(\mathbf{r})$ is expressed as in eq.(1) by using the plane-wave expansion method.

$$\mathbf{E}_q(\mathbf{r}) = \frac{1}{2\pi}\iint(\mathbf{a}(\mathbf{k_t})e^{j\mathbf{k}\cdot\mathbf{r}} + \mathbf{b}(\mathbf{k_t})e^{-j\mathbf{k}\cdot\mathbf{r}})dk_x dk_y \quad (1)$$
$$\mathbf{r} = \boldsymbol{\rho} + Z_0\mathbf{u_z} = x\mathbf{u_x} + y\mathbf{u_y} + Z_0\mathbf{u_z}$$

Taking into account only the radiated electric field in the region where z_n is positive, and assuming that there is no multiple reflection and no component which returns to the antenna, then $\mathbf{a}(\mathbf{k}_t)=0$ and the radiated electric field $\mathbf{E}_q(\mathbf{r})$ can be found using eq.(2).

$$\mathbf{E}_q(\mathbf{r}) = \frac{1}{2\pi}\iint(\mathbf{b}(\mathbf{k_t})e^{-j\mathbf{k}\cdot\mathbf{r}})dk_x dk_y \quad (2)$$
$$\mathbf{k} = \mathbf{k_t} + \gamma\mathbf{u_z} = k_x\mathbf{u_x} + k_y\mathbf{u_y} + \gamma\mathbf{u_z}$$
$$\gamma = \sqrt{k_0^{\ 2} - k_x^{\ 2} - k_y^{\ 2}}$$

Here, $\mathbf{k}$ is the wavenumber vector, and k_0 is the free space wavenumber. $\mathbf{b}(\mathbf{k}_t)$ is the vector plane-wave spectrum, and it can be obtained with eq.(3) by performing an inverse Fourier transform of eq.(2).

$$\mathbf{b}(\mathbf{k_t}) = \frac{e^{j\gamma z}}{2\pi}\iint(\mathbf{E}_q(\mathbf{r})e^{j\mathbf{k}\cdot\boldsymbol{\rho}})dxdy \quad (3)$$

The vector plane-wave spectrum $\mathbf{b}(\mathbf{k}_t)$ is expressed as in eq.(4) by using the transverse vector plane-wave spectrum $\mathbf{B}(\mathbf{k}_t)$.

$$\begin{aligned}\mathbf{b}(\mathbf{k_t}) &= \mathbf{B}(\mathbf{k_t}) - \frac{|\mathbf{k_t}|}{\gamma}b(1,\mathbf{k_t})\mathbf{u_z} \\ &= b(1,\mathbf{k_t})\mathbf{k}_1 + b(2,\mathbf{k_t})\mathbf{k_2} - \frac{|\mathbf{k_t}|}{\gamma}b(1,\mathbf{k_t})\mathbf{u_z}\end{aligned} \quad (4)$$

The transverse vector plane-wave spectrum $\mathbf{B}(\mathbf{k}_t)$ is given by eq.(5), using the radiated electric field $\mathbf{E}_t(\boldsymbol{\rho}, Z_0)$ expressed with the orthogonal unit vectors $\mathbf{e}_1$, $\mathbf{e}_2$ in the plane where near-field measurement was conducted.

$$\begin{aligned}\mathbf{B}(\mathbf{k_t}) &= b(1,\mathbf{k_t})\mathbf{k_1} + b(2,\mathbf{k_t})\mathbf{k_2} \\ &= \frac{e^{jZ_0}}{2\pi}\sum_{n=1}^{2}\mathbf{e_n}\iint E_{tn}e^{j\mathbf{k_t}\cdot\boldsymbol{\rho}}dxdy \\ &= \frac{e^{j\gamma Z_0}}{2\pi}\sum_{n=1}^{2}\overline{B_n}(\mathbf{k_t})\cdot\mathbf{e_n} \\ &= \sum_{n=1}^{2}B_n(\mathbf{k_t})\cdot\mathbf{e_n}\end{aligned} \quad (5)$$

Here, we have the following:

$$\mathbf{k_1} = \frac{\mathbf{k_t}}{|\mathbf{k_t}|} \quad , \quad \mathbf{k_2} = \mathbf{u_z} \times \mathbf{k_1}$$

$$\mathbf{E_t} = \mathbf{E_q} - E_z \mathbf{u_z} = E_{t1}\mathbf{e_1} + E_{t2}\mathbf{e_2}$$

$$\mathbf{e_1} = \sin\theta_p \mathbf{u_x} + \cos\theta_p \mathbf{u_y} \quad , \quad \mathbf{e_2} = \cos\theta_p \mathbf{u_x} + \sin\theta_p \mathbf{u_y}$$

$b(1,\mathbf{k_t})$,$b(2,\mathbf{k_t})$ indicate the plane-wave spectrum of the $E_{//}$ component (TM) and $E_{\perp}$ component (TE), respectively.

Equation (6) is obtained when eq.(5) is substituted in eq.(4).

$$\mathbf{b}(\mathbf{k_t}) = b(1,\mathbf{k_t})\mathbf{k_1} + b(2,\mathbf{k_t})\mathbf{k_2} - \frac{|\mathbf{k_t}|}{\gamma} b(1,\mathbf{k_t})\mathbf{u_z}$$

$$= \sum_{n=1}^{2} \left\{ B_n(\mathbf{k_t})\mathbf{e}_n - \frac{1}{\gamma} B_n(\mathbf{k_t})(\mathbf{e}_n \cdot \mathbf{k_t}) \cdot \mathbf{e_z} \right\} \tag{6}$$

$$= \sum_{n=1}^{2} B_n(\mathbf{k_t}) \frac{1}{\gamma} \{ \gamma \mathbf{e}_n - (\mathbf{e}_n \cdot \mathbf{k_t}) \cdot \mathbf{e_z} \}$$

Therefore, the radiated electric field $\mathbf{E}_q(\mathbf{r})$ and radiated magnetic field $\mathbf{H}_q(\mathbf{r})$ incident on the reflector can be found as in eq.(7) and eq.(8) by substituting eq.(6) in eq.(2).

$$\mathbf{E_q}(\mathbf{r}) = \frac{1}{2\pi} \sum_{n=1}^{2} \int B_n(\mathbf{k_t}) \frac{1}{\gamma} \{ \gamma \mathbf{e}_n - (\mathbf{e}_n \cdot \mathbf{k_t}) \cdot \mathbf{e_z} \} e^{-j\mathbf{k}\cdot\mathbf{r}} dK \tag{7}$$

$$\mathbf{H_q}(\mathbf{r}) = \frac{1}{2\pi} \sum_{n=1}^{2} \int \frac{1}{\gamma} \frac{1}{\omega\mu} \mathbf{k} \times \{ \gamma \mathbf{e}_n - (\mathbf{e}_n \cdot \mathbf{k_t}) \cdot \mathbf{e_z} \} e^{-j\mathbf{k}\cdot\mathbf{r}} dK \tag{8}$$

Figure 2 shows the reflector antenna coordinate system (x_m, y_m, z_m). In the figure, (x_n, y_n, z_n) is the coordinate system of near-field measurement shown in Fig. 1. For the point $\mathbf{r}_m$ on the reflector surface, $\mathbf{R}$ is taken to be the unit vector pointing from the origin $\mathbf{O}$ to the observation point p. If the distance R to the observation point is sufficient, the far field radiation pattern of the reflector antenna can be found with eq.(9) by using the current distribution method [6]. Here, $\mathbf{H_q}$ in eq.(9) can be found by repeatedly applying eq.(8) to each point $\mathbf{r}_m$ on the reflector surface.

$$\mathbf{E_s}(\mathbf{r}) = -\frac{j\omega\mu}{2\pi} \frac{e^{-jkR}}{R} \int_S \{ \mathbf{n} \times \mathbf{H_q} - [(\mathbf{n} \times \mathbf{H_q}) \cdot \mathbf{R}]\mathbf{R} \} e^{j\mathbf{r_m}\cdot\mathbf{R}} dS \tag{9}$$

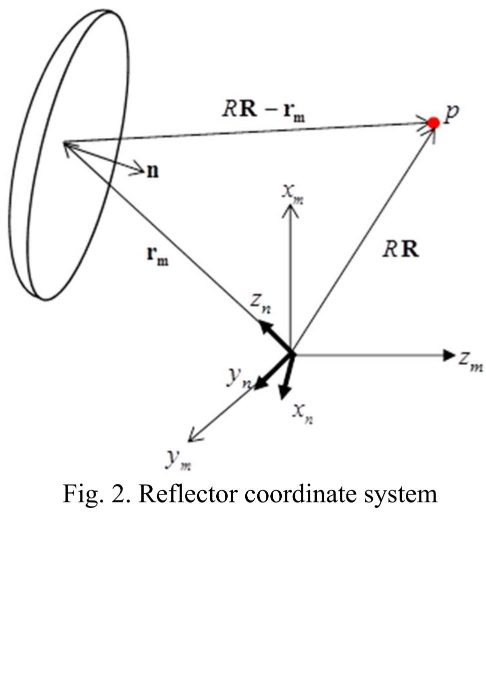
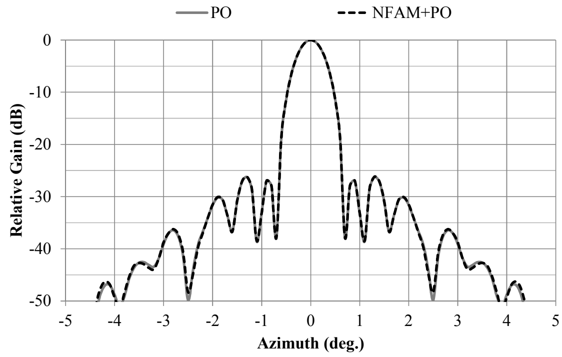


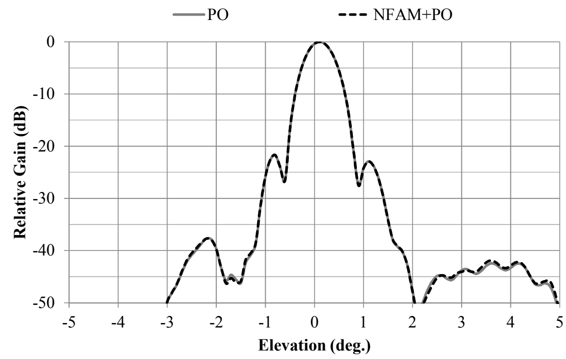
Fig. 2. Reflector coordinate system

3. Verification

The validity of the analysis method is examined for array-fed reflector antenna. The main reflector size is approximately 150 λ, the subreflector size is approximately 20 λ and the array-fed is 40 elements. Figure 3 shows a comparison of results calculated using only the current distribution method, and results calculated with this analysis method by using data simulating near-field measurement of the primary feed. It was confirmed that results in the two cases matched well.



(a) Horizontal plane



(b) Vertical plane

Fig. 3. Comparison of radiation patterns.

4. Conclusion

We investigated a radiation pattern analysis method for reflector antennas using near-field measurements of primary feed. The validity of this analysis method was verified by the calculation result applied to array-fed reflector antenna. This antenna has received a lot of attention for onboard satellite of the next generation in recent years. The characteristic of the primary feed greatly influences array-fed reflector antenna. We will consider this analysis method to be effective for the evaluation of such array-fed reflector antenna.

References

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